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Implications of present and upcoming changes in bioclimatic potential for energy performance of residential buildings

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ABSTRACT

Bioclimatic potential analysis is one of the starting points for bioclimatic building design. However, as climate changes are being brought into the spotlight, bioclimatic potential is being put into question as well, because traditionally used passive strategies at a specific location may no longer represent properly balanced approach. Therefore, the purpose of this paper was to systematically evaluate bioclimatic potential of the selected five locations. At these locations, bioclimatic potential was observed separately for each of the last five decades. In the second part, present and future energy performance of one bioclimatic and one non-bioclimatic real residential building was simulated. The results show that yearly balance between heating and cooling passive strategies changed through time in all the locations. For example, the use of overheating prevention strategies is becoming more significant than it used to be in the past. Specifically, the period of year when shading is needed to achieve thermal comfort increased by 2–7% points, depending on location. Energy performance analysis of the selected buildings showed that by 2050 both analysed buildings will become cooling dominated and that by 2050 the current design solutions in bioclimatic buildings will become irrelevant or at least extremely inefficient. In general, in temperate climate zone the prevailing bioclimatic strategies integrated in architecture focus on heating season. Therefore, bioclimatic strategies in a particular location must be re-evaluated in order to design new and retrofit existing energy efficient contemporary buildings with comfortable indoor thermal conditions.

1. Introduction

The 2015 Paris agreement on climate change set goals and limits in order to reduce further increment of global air temperatures. According to European Directives, lowering of environmental impact of buildings [1] and improving their energy efficiency [2,3] are key elements in achieving those objectives. Evidence is mounting that in the light of increasing awareness about the use of natural resources and the protection of the environment, the importance of energy performance of buildings is continuously growing. Simultaneously, the indoor thermal comfort is also gaining on importance as it plays a crucial role in the perception of “healthy homes” [4]. Therefore, the aforementioned requirements introduced by EU Directives [2,3] encourage accelerated progress in the field of energy efficient buildings, whereby near-zero energy buildings (nZEB) have become a technological reality as well as necessity. However, with the application of previously mentioned regulations the impact of buildings on energy use and climate change is not a resolved issue, as crucial role towards achieving sustainable society should be played by climatically adaptable building design, also resulting in higher level of indoor comfort. Hence, greater attention is paid to the correlation between a selected design approach and the corresponding performance outputs.

All the above mentioned aspects can be entirely or at least to some degree addressed by bioclimatic building design. A building can be declared as bioclimatic when it efficiently uses climatic resources of its location, primarily with the help of building envelope elements [5]. In order to design buildings in a way that they adapt to climate as much as possible, a balance between the chosen heating and cooling passive strategies must be obtained. Accordingly, if the design goal is a thoughtful choice of appropriate bioclimatic strategies, it is necessary to evaluate the climate characteristics at a specific location. One way of assessing location's bioclimatic potential is through the use of bioclimatic chart. This approach was originally pioneered by Olgyay [6] in 1963. With bioclimatic chart, elementary climate data, such as dry-bulb air temperature and relative humidity, can be used to determine the most promising passive design strategies at a specific location. Nevertheless, it has to be stressed that the conventional approach of bioclimatic analysis through bioclimatic charts does not directly incorporate the influence of solar radiation. Thus, the interpretation of results can be insufficient and misleading, because the impact of solar radiation on

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the selection of passive strategies can be substantial.

Several studies have been conducted (see Refs. [7–15]), which involved the calculation of bioclimatic conditions or bioclimatic potential at the selected locations. The referenced studies underlined the importance of such building design and consequential adaptation to the local climate. In order to design a contemporary bioclimatic building, two different approaches can be selected. The first one is replication of bioclimatic patters found in local vernacular architecture (e.g. see Refs. [16–19]), adapted to the climatic characteristics through centuries. On the other hand, the second approach utilizes climate analysis in order to independently determine the most promising design strategies on the basis of dominant climatic patterns. Such approach was shown by Pajek and Košir [14] on the example of the European Alpine-Adriatic region, by Alonso Monterde et al. [20] for the Valencian region in Spain or by Yang et al. [21] for five major climatic zones in China. Notwithstanding the existing studies, Dubois et al. [22] highlighted that knowledge transfer between research and practice in building engineering is insufficient. The latter reflects in the fact that, in general, professionals at an early stage of the design process rarely adopt tools to support the design for climate adaptation. Accordingly, either novel, broadly unverified solutions are practiced or examples from vernacular architecture are replicated as a baseline for the choice of the most appropriate passive strategies at a specific location. Both approaches are frequently used by contemporary designers [23]. Specifically, climate adaption is considered by designers as one of several design-related concerns [21]. Thus, building's ability to adapt to climate has a potential to encourage designers to critically reconsider this subject [24]. The design issue is further deepened as strategies used in vernacular architecture are based on the past climatic conditions. Such approach would not represent a problem if climate characteristics were in fact not a dynamic process. In this respect, Tejero-González et al. [25] highlighted that careful use of available climate data must be done, because it only represents probable occurrence of conditions. Moreover, in the last decades the climate has been in the state of accelerating change and will continue to change, according to several conducted studies [26–28]. The changes in the climate are designated as fast and of large scale. Specifically, the mountainous regions were shown by Miró et al. [28] to be most affected by increased temperatures due to potential climate change, while the least affected were lowlands and inland valleys. Potential consequences of such changes for urban areas could reflect in higher flood risks, intensified urban heat islands, lower indoor comfort and occupant productivity as well as increased heat related health risks [29]. Opposing the stated negative effects, higher temperatures can also decrease energy use for heating and increase the options for outdoor activities and tourism [29]. If the predicted effects of climate change unfold, its potential implications for current and future buildings may be immense. Therefore, Pajek and Košir [14] highlighted that bioclimatic potential at some locations should be re-evaluated or even further – predicted by future weather projections. This is of paramount importance, because some passive design strategies, traditionally implemented in local vernacular architecture, might no longer represent the best suited approach to climatically adapted building design. Similarly, the problem is also present in "non-bioclimatic" contemporary buildings, as it was shown by Fezzioui et al. [30]. Their simulation of modern house under desert climate conditions revealed that because the building is not adapted to local climate, except for the air-conditioning, there is in summer no other solution that can ensure indoor thermal comfort. However, it must be emphasised that not only the technical characteristics of buildings should be addressed, but also how the occupants perceive the indoor thermal environment [31]. To sum up, it can be argued that climate is changing and that this will have an impact on indoor thermal conditions in buildings.

According to the challenges of the future, such as climate change, a conceptual leap in (bioclimatic) building design will be necessary. Particularly, current building design paradigms should be replaced by new approaches, which will consider the state of the current and future climate [14,32]. Such approach was already presented by Huang and Gurney [33], Shen and Lior [34] and Shen [35] in the US, Yu et al. [36] and Cao et al. [37] in China, Nik [38] in Italy and Sweden, van Hooff et al. [39,40] and Hamdy et al. [41] in the Netherlands, Berger et al. [42] in Austria, Pierangioli et al. [43] in Italy and Andrić et al. [44] for various climate zones. The referenced studies dealt with the energy performance of different types of buildings (e.g. office, residential, etc.), which were evaluated according to the present and/or future climate projections. Passive and/or active building strategies were considered. Several of the studies (see Refs. [40,41]) also demonstrated the potential of implementing passive measures (e.g. shading devices) in older buildings. Berger et al. [42], Cao et al. [37] and Pierangioli et al. [43] emphasised that buildings dominantly designed for the heating season will have to be retrofitted in accordance with the modern challenge of added cooling demands. In this context, Li et al. [45] underlined that climate change will have the most significant impact in warmer climates dominated by cooling demand and that in severely cold climates a reduction in heating demand would prevail over the modest increase in summer cooling. Although all the referenced studies dealt with the impact of climate change on present and future energy demand of either commercial, public or residential buildings, there is still lack of understanding of bioclimatic architecture and its adaption to the future climate. No recent study that we are aware of addresses this issue.

As has been noted, the conducted studies mostly consider only hypothetical typical (non-bioclimatic) building models and their future energy performance, despite the fact that also the existing building stock can be crucially affected by climate change, especially if these buildings were adapted to past climate conditions. Beside the bioclimatic approach to the design of new buildings, the renovation of the existing building stock in accordance with bioclimatic strategies will have to be encouraged as well, in order to address climate adaptability of the entire building stock. Hence, identification of past, current and future trends in bioclimatic potential of a location is needed. In other words, the question is whether the present "climate-balanced" buildings will still be appropriate for the climatic conditions of tomorrow. Therefore, the purpose of this paper is to thoroughly evaluate bioclimatic potential of five different locations in Slovenia, Europe. Moreover, bioclimatic potential was evaluated for the last five consecutive decades, in order to identify potential changes and any identifiable pattern. Additionally, bioclimatic potential was predicted for the next two decades. Although the reviewed literature showed that predicted energy performance of buildings is gaining on importance and is widely studied, it is not completely clear how bioclimatically designed buildings will respond to the climate change. Therefore, present and future energy performance of one bioclimatic and one non-bioclimatic real residential building was simulated. In particular, the main contribution of the paper to science and building practice is that the selected bioclimatic strategies, which are most commonly used in the temperate climate, and their effect on energy efficiency of buildings were evaluated for the present and the future. This has a significant impact on current and future decisions in building design and energy policy development.

2. Methods

2.1. Selected locations

For the purpose of this paper five locations in the Central European country of Slovenia were chosen in order to represent characteristic climate conditions that occur in Slovenia (Fig. 1) located in temperate climate zone of Central Europe:

- Portorož – 45°30′N 13°34′E, altitude: 31 m
- Murska Sobota – 46°39′N 16°09′E, altitude: 189 m
- Novo mesto – 45°47′N 15°10′E, altitude: 202 m
- Ljubljana – 46°03′N 14°30′E, altitude: 295 m

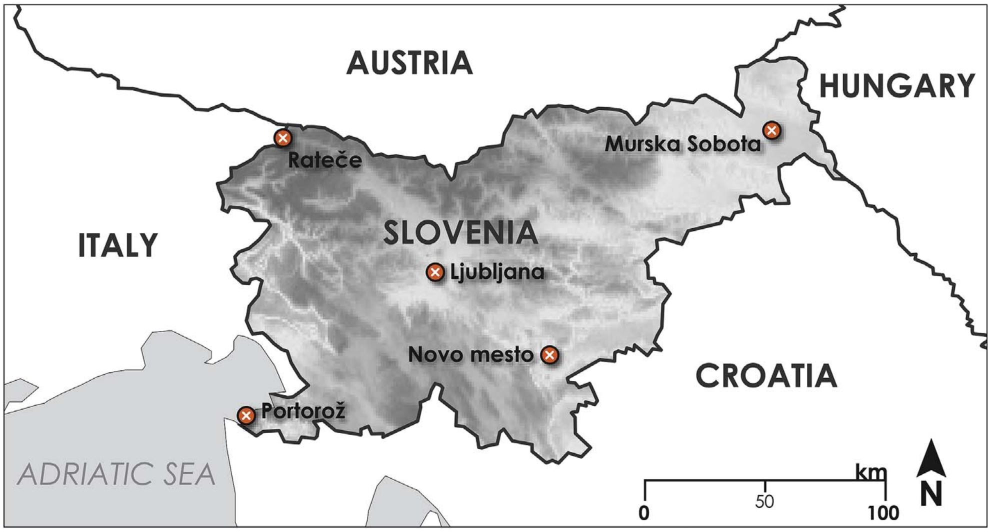


Fig. 1. Selected locations.

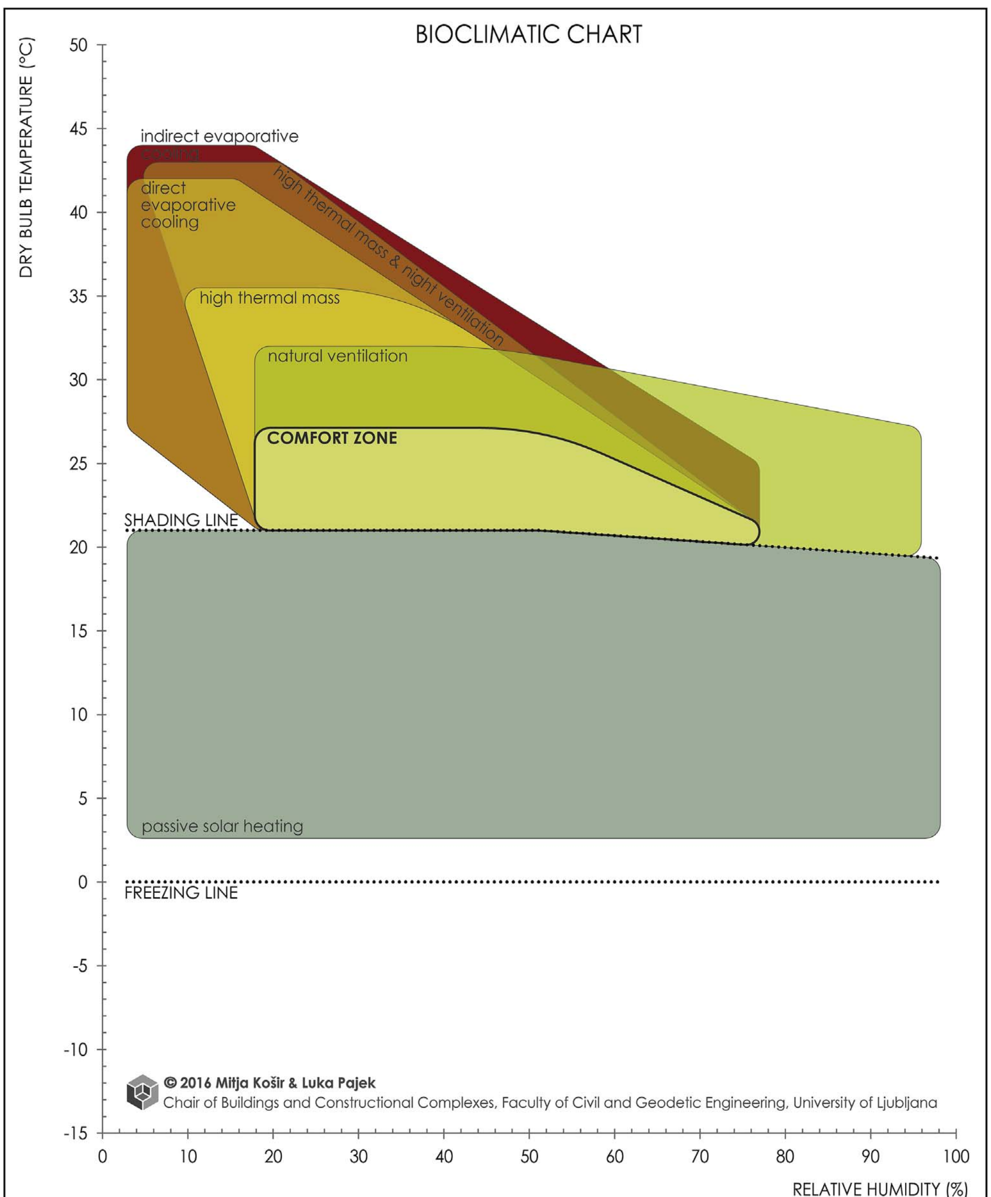


Fig. 2. Bioclimatic chart used in the analysis conducted with BcChart v1.0 tool.

Table 1
Bioclimatic potential as calculated by BcChart with suggestions of bioclimatic design strategies to be used to utilize the potential.

Label	Bioclimatic potential		Bioclimatic design strategy [16,52]
V	high thermal mass and/or natural ventilation and shading needed	S shading needed ($S = V + C_{sh}$)	• external shading • intensive ventilation (i.e. night purge) • high thermal mass of buildings • phase change materials in lightweight buildings
C_{sh}	comfort achieved with shading		• external shading
C_z	comfort achieved ($C_z = C_{sn} + C_{sh}$)		
C_{sn}	comfort achieved with solar irradiation	S_n solar irradiation needed ($S_n = C_{sn} + R + H$)	• equatorially oriented openings (i.e. direct solar gains)
R	potential for passive solar heating		• equatorially oriented openings (i.e. direct solar gains) • sunspace, Trombe-Michel wall, etc.(i.e. indirect solar gains) • partial conventional heating necessary
H	no potential for passive solar heating		• conventional heating necessary

- Rateče – 46°29′N 13°42′E, altitude: 864 m

Although all of the selected locations could be characterised by Köppen-Geiger climate classification type Cfb (temperate, without dry season, warm summer), Slovenia's climate is regarded as highly diversified; hence large variability within the same climate type is common [14]. For example, the analysed location of Portorož has a sub Mediterranean climate (Cfa according to Köppen-Geiger classification) due to its position next to the Adriatic Sea. Similarly, Rateče has colder climate than other locations due to its Alpine location; therefore, it represents a transition from Cfb to Dfb climate types.

2.2. Data analysis

2.2.1. Preparation of meteorological data

In order to analyse the bioclimatic potential of the selected locations, historical weather data were obtained for every year between 1961 and 2015. In particular, the acquired weather data were as follows: average (T_{avg}), average maximum ($T_{max,avg}$) and average minimum ($T_{min,avg}$) yearly air temperature, average maximum ($T_{max,i}$) and average minimum ($T_{min,i}$) daily air temperature and relative humidity ($RH_{max,i}$ and $RH_{min,i}$) for every month, and average ($G_{avg,i}$) and average maximum ($G_{max,i}$) daily global solar irradiance on horizontal plane for every month. All the acquired data were obtained from the archives of automatic weather stations, which were all located in urbanised locations. All of the climate data were provided by Slovenian Environment Agency [46].

For the energy performance simulations the necessary hourly weather data were acquired from the online TMY Generator provided by the Joint Research Centre at the European Commission [47] for the selected representative location (i.e. Murska Sobota). The weather file was generated using measured data for the 2006 to 2015 decade. This file was later used to generate predicted weather files for 2020 and 2050 using HadCM3 (i.e. Hadley Centre Coupled Model, version 3) modelled climate change predictions provided by the Intergovernmental Panel on Climate Change [48]. Weather files with future climatological characteristics were obtained using the CCWorldWeatherGen tool [49] developed by Jentsch et al. [50] at the University of Southampton.

2.2.2. The underlying theory of bioclimatic potential calculations

The bioclimatic potential of locations was calculated for a typical residential building. In order to determine the bioclimatic potential for each location, the BcChart 1.0 tool was used [51]. With the BcChart tool, elementary climate data (T_{avg}, $T_{max,avg}$, $T_{min,avg}$, $T_{max,i}$, $T_{min,i}$, $RH_{max,i}$, $RH_{min,i}$, $G_{avg,i}$, $G_{max,i}$) were analysed and bioclimatic charts were plotted (Fig. 2). Furthermore, location's bioclimatic potential was calculated. The software is based on the theory of Olgyay's bioclimatic chart [6] and upgraded with the calculation of daily substitutive temperature (T_{sub}) through which the influence of actually received solar irradiation is incorporated into calculation. T_{sub} represents a reciprocal air temperature under the influx of solar irradiation. This results in a newly introduced C_{sn} value, which represents the time when human comfort is achieved with the utilization of available and received solar energy. Comfort zone (C_z), as defined by Olgyay, is placed between 21 and 27 °C and 18 and 77% relative humidity (Fig. 2). At higher values of relative humidity (> 50%) and higher temperatures (> 21 °C) the comfort zone is narrower. The temperature at the bottom of the comfort zone (i.e. 21 °C) coincides with the shading line. All temperature and relative humidity combinations that fall above this line will result in a need for shading (S), and those bellow it in the need for solar irradiance (R or H). Similar is true at the upper limit of the comfort zone, where the combinations above it (V) will result in the need for shading and other passive cooling strategies as well (e.g. intensive natural ventilation, high thermal mass, etc.). Correspondingly, comfort can be directly achieved either by shading (C_{sh}), use of solar energy (C_{sn}) or indirectly by passive or active measures (Table 1). It is assumed that human comfort is calculated for a person wearing customary indoor clothing (1 Clo), engaged in sedentary or light muscular work (M = 126 W) and the air movement is presumed to be 0.45–0.90 m/s. The exact methodology, based on which the bioclimatic potential of a location is determined by BcChart software, is presented in greater detail in the paper by Pajek and Košir [14].

As a result of the BcChart analysis, the time expressed in %, calculated either on yearly or monthly level, when the plotted combinations of temperature, relative humidity and solar irradiance fall either in or out of the comfort zone (C_z), is defined. For example, bioclimatic potential, expressed in %, defines the percentage of a particular month, when certain bioclimatic strategy is favourable (e.g. 10% of days in May shading should be used) in order to achieve the desired thermal comfort entirely with passive measures. Periods that determine the principal passive strategies are calculated and denominated as presented in Table 1.

2.3. Selected buildings and energy performance simulations

In order to directly connect the obtained results of bioclimatic potential analysis with practical implications, two existing typical residential buildings were selected. The first building (Fig. 3a) is a typical non-bioclimatic building (labelled as non-BC building) frequently found in Slovenian building stock. The second one (Fig. 3b) is a typical bioclimatic building (labelled as BC building), which is an example of commonly found contemporary energy efficient building, believed to be a good example of bioclimatic architecture. The two selected buildings

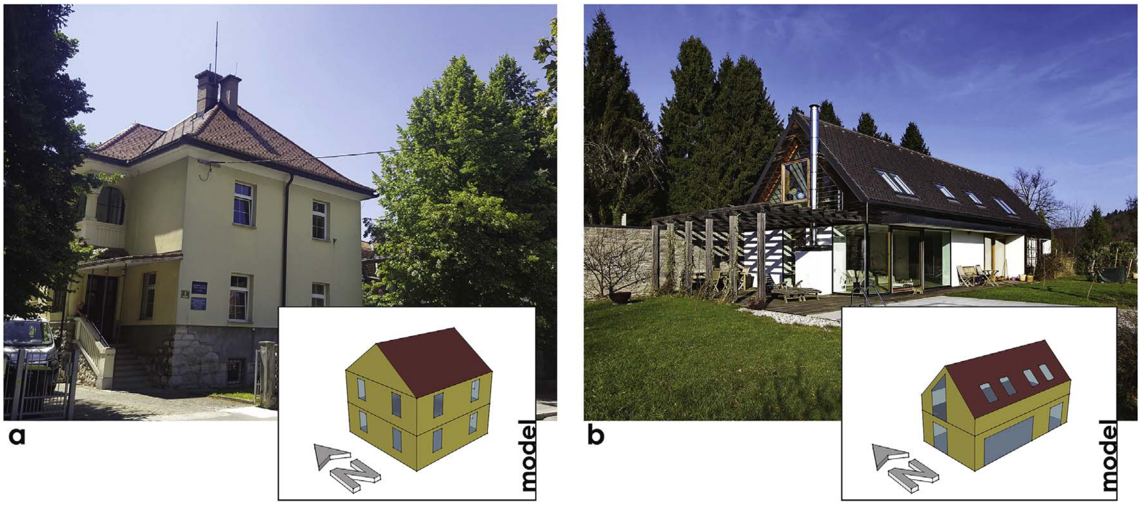


Fig. 3. Examples of two typical residential buildings with the corresponding OpenStudio geometric models (Fig. 3b photo by VELUX Group).

were used as examples for the definition of appropriate simulation models (Fig. 3). The floor area of both models is 162 m^2. The non-BC building has a square floor plan (i.e. 9 by 9 m), while the BC building has a rectangular shape with dimensions of 6.5 by 12.5 m. Both buildings have two floors and are oriented according to the cardinal axes, in case of BC building the longer façade faces south. The ratio between the floor area and the surface of windows is 15% (i.e. 25.2 m^2) for the non-BC building and 24.5% (i.e. 39.7 m^2) for the BC building. The distribution of windows in the case of non-BC building is almost uniform with 7.2 m^2 of windows per south, east and west oriented façades, while there are 3.6 m^2 of north oriented windows. In case of the BC building the distribution of windows is geared towards solar energy harvesting. Therefore, the south oriented windows including skylights amount to 25.4 m^2, while the remaining 14.3 m^2 of windows are distributed between the east and the west façades.

In the energy performance analysis two types of building envelopes were simulated. The first one represents a typical building constructed during the 1970s (labelled as OLD) and the other one reflects the minimum requirements of current Slovenian Technical guidelines about efficient use of energy in buildings [53] (labelled as NEW). The properties of both building envelope configurations as well as data on internal heat gains, lighting loads, ventilation and heating and cooling temperature set-points are presented in Table 2. In order to check the influence of window shading, as one of the most commonly practiced bioclimatic design strategies for overheating prevention, on the energy performance of the analysed buildings, the external aluminium venetian blinds were used on all windows. Shading is active from 1st of May till 30th of September. Blinds are extended and the blades are tilted at an angle of 45°, if the received solar irradiation on the window exceeds 120 W/m^2. Otherwise windows are unobstructed. Energy performance simulations were performed using EnergyPlus [54] and OpenStudio SketchUp plugin [55,56].

2.4. Limitations of the applied methodology

Firstly, it has to be stressed that the results of the presented bioclimatic analysis can only represent general guidelines for a particular analysed building type and location. The bioclimatic potential was calculated for a typical residential building in an urbanised environment. Therefore, the results are directly applicable only to similar buildings. One limitation of the methodology is that the internal heat gains cannot be taken into account when calculating bioclimatic potential. Another limitation, however of a lesser concern, is also that the behaviour of wind flow over time was not analysed. Nevertheless, the wind flow is not directly included into the bioclimatic potential analysis

Table 2
Building envelope characteristics, ventilation, internal heat gains and temperature set-point parameters.

			Envelope type	
			OLD	NEW
Envelope characteristics	U_{wall}	(W/m^2K)	0.90	0.28
	U_{roof}	(W/m^2K)	0.60	0.20
	U_{floor}	(W/m^2K)	0.90	0.30
	U_{window}	(W/m^2K)	2.50	0.70
	g_{window}	(−)	0.75	0.53
Ventilation	n	(ACH)	0.50[a] (0.80, May to September)	
Internal heat gains	*occupants*	(W)	280[b]	
	el. equip.	(W)	972[c]	
	lights	(W)	486[c]	
Temperature set-point	$T_{heating}$	(°C)	21.0	
	$T_{cooling}$	(°C)	26.0	

[a] Corresponding to minimum requirements defined in EN 15251 [57].
[b] 70 W/occupant [58], 4 occupants, schedule according to ASHRAE Standard 90.1–2004 [59].
[c] Value and schedule according to ASHRAE Standard 90.1–2004 [59].

but is only exposed as needed or not (V values – natural ventilation needed), which can also be achieved by draft, stack ventilation or even mechanical ventilation. Due to insufficient historical data about solar radiation, all the conducted bioclimatic analyses were made on the basis of daily global solar irradiance on horizontal plane ($G_{avg,i}$, $G_{max,i}$) for the year 2015. It can be speculated that this simplification overestimates the influence of solar radiation during the earlier decades, when we can presume that lower ambient temperatures also coincided with lower solar irradiance. This means that using 2015 data for solar irradiance during these periods would have a far greater influence than the actual irradiance had. Another limitation is that the building energy need for artificial lighting was excluded from the analysis. Thus, the possible effect of potentially applied shading on the increase in electricity demand for lighting cannot be estimated. For this reason, the application of shading devices should be extremely deliberate, because they can significantly affect daylighting in buildings [60,61].

3. Results and discussion

The results of the study are presented in two steps. Firstly, the bioclimatic analysis and bioclimatic potential calculation at all the

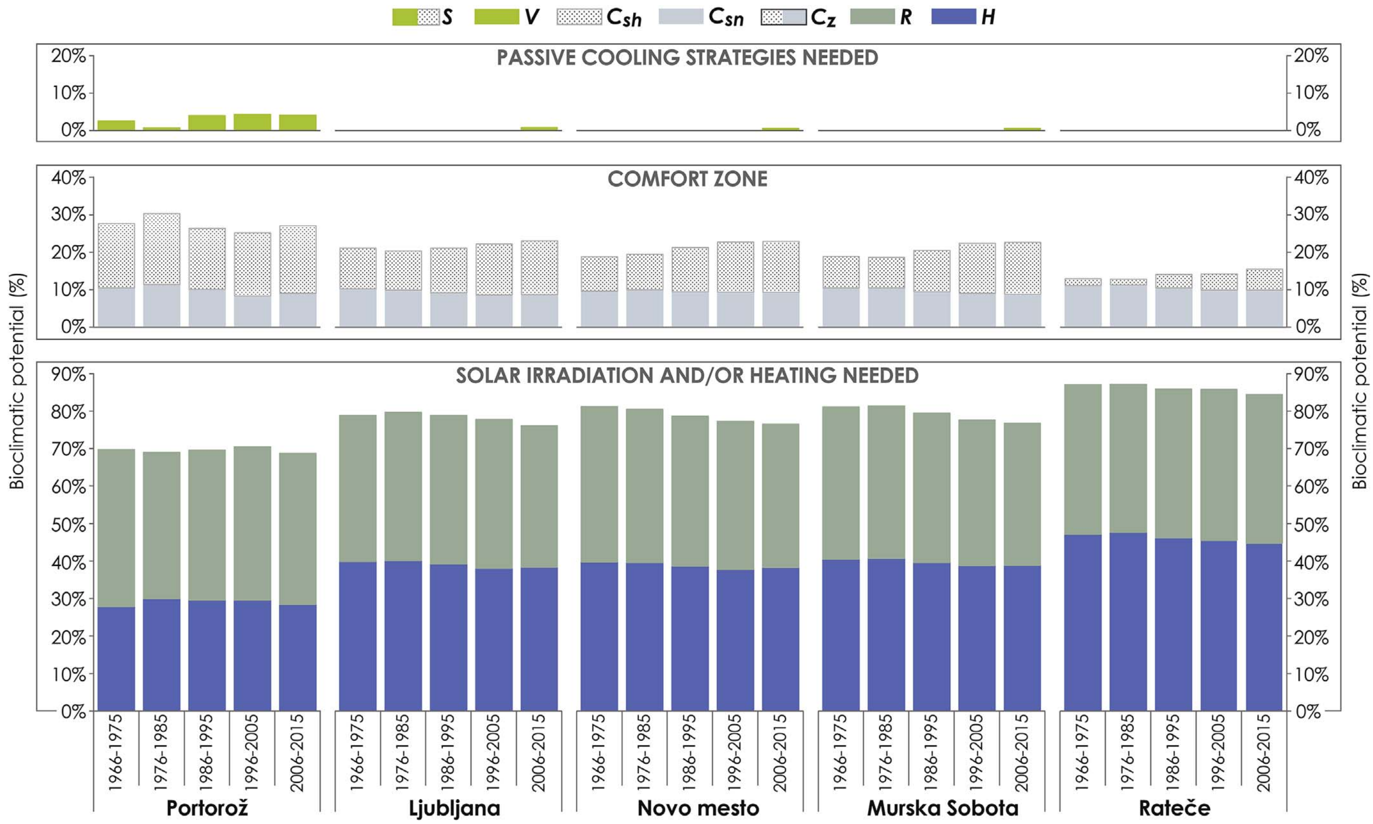


Fig. 4. Yearly bioclimatic potential of the analysed locations calculated separately for each decade. V – high thermal mass and/or natural ventilation and shading needed, C_{sh} – comfort achieved with shading, S (i.e. $V + C_{sh}$) – shading needed, C_{sn} – comfort achieved with solar irradiation, C_z (i.e. $C_{sh} + C_{sn}$) – comfort zone R – potential for passive solar heating, H – no potential for passive solar heating.

selected locations were carried out and the results are presented in subsection 3.1. Secondly, present and predicted future energy performance of the selected two real residential buildings was simulated and the results are presented in subsection 3.2.

3.1. Bioclimatic evaluation

Bioclimatic potential was calculated for the selected five locations. It determines the time share of the year (or month) in % when particular passive building design measures are efficient at facilitating building occupant comfort. Accordingly, the most promising passive design strategies and their corresponding yearly ratio were calculated using the BcChart software. Although Fig. 4 represents yearly data, the calculations of bioclimatic potential were conducted using monthly climatological data (i.e. monthly daily averages). Therefore, the yearly bioclimatic potential is a summation of monthly values represented as a share with respect to the whole year. Similarly, when calculating the bioclimatic potential in each of the analysed decades, monthly daily averages were used, calculated discretely for each of the consecutive decades. Bioclimatic potential at each location was observed separately for each decade of the last fifty years (1966 till 2015). The results are presented in Fig. 4.

If bioclimatic potential at all the locations in the last decade (2006–2015) is compared to the first analysed decade, namely 1966–1975, it can be noticed that comfort zone ($C_z = C_{sh} + C_{sn}$) is expanding (see Fig. 4). However, the way how this is achieved, specifically the ratio between C_{sh} (i.e. comfort achieved with shading) and C_{sn} (i.e. comfort achieved with solar irradiation), significantly altered (Table 3). In particular, in Murska Sobota, the C_{sh}/C_{sn} ratio changed from 0.80 in 1966–1975 to 1.57 in the last decade (2006–2015). This means that in the past, occupant comfort on yearly level was predominantly achieved with the utilization of solar energy (e.g. direct

Table 3
Values of S (i.e. $V + C_{sh}$) – shading needed, C_{sh} – comfort achieved with shading, C_{sn} – comfort achieved with solar irradiation and the ratio between C_{sh}/C_{sn} for each of the last five decades.

		Portorož	Ljubljana	Novo mesto	Murska Sobota	Rateče
1966–1975	S (%)	20.2	10.8	9.1	8.4	1.8
	C_{sh} (%)	17.6	10.8	9.1	8.4	1.8
	C_{sn} (%)	10.0	10.3	9.7	10.5	11.1
	C_{sh}/C_{sn}	1.76	1.05	0.94	0.80	0.16
1976–1985	S (%)	19.7	10.4	9.5	8.1	1.5
	C_{sh} (%)	19.0	10.4	9.5	8.1	1.5
	C_{sn} (%)	11.4	9.9	10.0	10.5	11.3
	C_{sh}/C_{sn}	1.67	1.05	0.95	0.77	0.13
1986–1995	S (%)	20.3	11.9	11.8	11.0	3.6
	C_{sh} (%)	16.3	11.9	11.8	11.0	3.6
	C_{sn} (%)	10.1	9.2	9.5	9.5	10.5
	C_{sh}/C_{sn}	1.61	1.29	1.24	1.16	0.34
1996–2005	S (%)	21.1	13.6	13.3	13.3	4.3
	C_{sh} (%)	16.8	13.6	13.3	13.3	4.3
	C_{sn} (%)	8.4	8.6	9.4	9.1	9.9
	C_{sh}/C_{sn}	2.00	1.58	1.41	1.46	0.43
2006–2015	S (%)	22.7	15.3	14.2	14.6	5.8
	C_{sh} (%)	18.5	14.4	13.6	13.8	5.8
	C_{sn} (%)	9.1	8.7	9.3	8.8	10.0
	C_{sh}/C_{sn}	2.03	1.66	1.46	1.57	0.58

solar gains), and far less by shading during hotter parts of the year. However, in the last decade the situation switched, as comfort zone on the yearly level is far more likely achieved by shading (i.e. solar protection) than by the utilization of solar radiation (Table 3 and Fig. 4). Specifically, the alteration of the trend occurs as a consequence of the increase in the C_{sh} value and simultaneous decrease in the C_{sn} value, which is the result of increase in ambient temperatures (the largest in Novo mesto with $\Delta T_{avg} = 2.8$ K and the lowest in Rateče with $\Delta T_{avg} = 1.8$ K). Similar development was also identified at all other locations, with the exception of Portorož, characterized by sub Mediterranean climatic characteristics, where shading has been the predominant strategy for achieving comfort all along. Specifically, the C_{sh}/C_{sn} ratio for the location of Portorož grew from 1.76 for the 1966–1975 period to 2.03 for the 2006–2015 period. The identified increment of the C_{sh} value emphasises the fact that although the bioclimatic potential at all the analysed locations has been shifting towards the extension of the comfort zone, greater attention is needed during the cooling season, as shading of transparent building elements is apparently becoming a priority issue. However, the importance of providing sufficient solar gains for passive solar heating, reflected through the C_{sn} as well as R values, is decreasing. Furthermore, in the last decade the appearance of the V value (i.e. high thermal mass and/or natural ventilation and shading needed) was also identified at several locations (i.e. Ljubljana, Novo mesto, Murska Sobota), which can be observed in Fig. 4. This is a characteristic typically linked with the Mediterranean climate [14] (e.g. Portorož). Moreover, highly urbanised locations, such as Ljubljana, are additionally exposed to overheating due to the phenomenon of urban heat island, which is in the case of Ljubljana further intensified by its geographical location at the bottom of a basin.

The consequence of comfort zone extension and the appearance of the V value in the last decades is the reduction of the R (i.e. potential for passive solar heating) and H (i.e. no potential for passive solar heating) values (Fig. 4). To summarise, bioclimatic potential analysis conducted using the available climatic data for the selected locations shows a steady transition towards overheating prevention strategies (C_{sh} and V) and a decrease in the importance of bioclimatic strategies designed for the utilization of solar gains (C_{sn} and R). Therefore, if existing buildings are not designed with appropriate passive elements for overheating prevention (i.e. effective shading), the actual achieved comfort (C_z would be equal or close to C_{sn}) at all the locations would in fact be decreased during the analysed fifty years (Table 3).

3.1.1. Detailed monthly bioclimatic potential analysis

Due to the identified shift in the calculated bioclimatic potential on a yearly level, the situation was further investigated on a monthly level in order to get a closer look at the phenomenon at work. The most characteristic change of the relationships between bioclimatic potential components and the corresponding passive strategies over the analysed five decades was recognised in Murska Sobota (see Fig. 4 and Table 3). The trend at similar locations (i.e. Novo mesto and Ljubljana) is comparable. Therefore, monthly breakdown of bioclimatic potential of Murska Sobota for the first analysed decade (1966–1975, see Fig. 5, bottom) and the last one (2006–2015, see Fig. 5, top) is presented. Because Rateče and Portorož represent locations with different climatic characteristics (Dfb and Cfa, respectively, according to Köppen-Geiger climate classification), their monthly breakdowns of bioclimatic potential for the first and the last analysed decade are also presented and can be observed in Figs. 6 and 7.

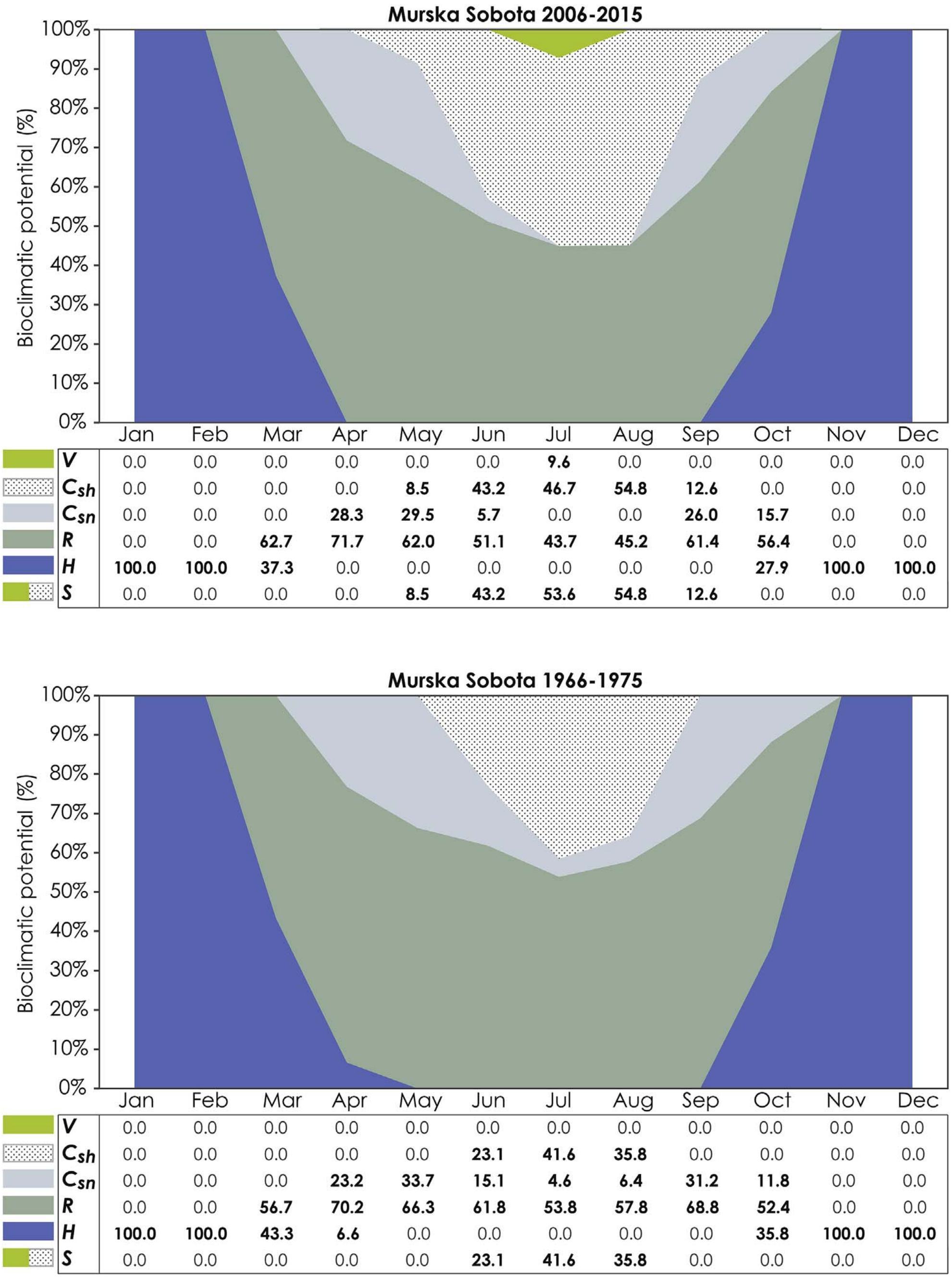
Observing Fig. 5, the aforementioned decrease in the R and H values on the yearly level (Fig. 4) is mostly limited to the time of year when transition between heating and cooling occurs. The latter can be, for example, recognised in transitional months, such as April or October (Fig. 5). In particular, bioclimatic potential of Murska Sobota in April shifted towards more comfortable conditions with a decrease of the H value from 6.6 to 0.0% (Fig. 5). Consequently, the C_{sn} and R values increased. If the bioclimatic potential, presented in Fig. 5, is observed during the summer months of June, July and August, a substantial increase of the S value (i.e. shading needed, $S = V + C_{sh}$) in the last 50 years can be identified. For instance, for Murska Sobota the S value in June almost doubled, rising from 23.1% (1966–1975) to 43.2% (2006–2015). In addition to the increase of the S value, the importance of shading is no longer limited exclusively to the summer months, as its occurrence is spreading into May and October (Fig. 5). Surprisingly, the C_{sn} value during hotter months is decreasing, most likely due to higher air temperatures. Thus, the influx of additional solar radiation is not desired in the same extent as it was in the past. Moreover, in comparison to the previous decades, the last decade the incidence of the H value in is increasingly becoming limited only to the months from November to February. A result of the described trend is the growing importance of overheating prevention in the design of new and renovation of existing buildings.

Similar trends can also be observed in Fig. 6, where monthly breakdown of bioclimatic potential for Rateče with colder climate (Dfb according to Köppen-Giger climate classification) is presented. Again, a significant increase of the S value in June, July and August can be recognised. Specifically, in the last five decades in July and August the S value increased by 17–18% points, while previously (1966–1975) shading was limited only to the months of July ($S = 14.4\%$) and August ($S = 6.9\%$). However, viewed as a whole, comfort zone in Rateče expanded and unlike in Murska Sobota, it still is mostly attributed to the utilization of solar energy and not shading, although the C_{sh}/C_{sn} ratio is on the rise. In particular, the C_{sh}/C_{sn} ratio increased from 0.16 in the first analysed decade to 0.58 for the 2006–2015 period (Table 3). Fig. 6 also clearly shows that in Rateče the H values did not record any significant change. For instance, the difference is most obvious in April, where the H value dropped by 9% points.

Lastly, the monthly breakdown of bioclimatic potential for Portorož with sub Mediterranean climate is presented in Fig. 7. At this location, the most apparent difference that occurred in the last five decades is the increase of the V value. The increase is most obvious in July, where the period of month with high thermal mass and/or natural ventilation and shading needed rose by 14% points. Similar to other locations, the S value in spring and summer months increased, with the highest increment in May, i.e. from 5.5% in 1966–1975 to 19.9% in 2006–2015 (Fig. 7). Accordingly, to achieve comfort in hotter months (i.e. June till August), solar irradiation is no longer desired (i.e. $C_{sn} = 0\%$). Nevertheless, the R value is still present, which means that in Portorož either shading is needed, or comfort can be partially achieved with the utilization of solar energy, which may not be available at the time (i.e. in the morning or during the night).

3.1.2. Comments on the results of bioclimatic potential analysis

The conducted bioclimatic potential analysis highlighted that the time of year when climatic conditions fall within the comfort zone (C_z) is expanding. However, it has to be stressed that the increase in comfort zone appears due to the increase in the C_{sh} (i.e. comfort achieved with shading) value, while at the same time the value of C_{sn} (i.e. comfort achieved with solar irradiation) is in fact being reduced. For example, in the case of Murska Sobota the C_z value increased by 3.7% points, while C_{sn} reduced by 1.7% points and C_{sh} increased by 5.4% points during the last 50 years. The only exception to the described trend is the location of Portorož, where the C_z value slightly decreased by 0.9% points, mainly due to the 1.6% point increase in the V value (i.e. need for intensive ventilation and/or high thermal mass), which also testifies to the increase in ambient air temperatures over the analysed time period. The calculated values of S (i.e. shading needed) are on the rise even in Rateče, the coldest of the analysed locations. There, the S value tripled, from 1.8% in 1966–1975 to 5.6% for the last decade (2006–2015). Similar results are also evident for other locations. Thus, the importance of passive strategies for the reduction of overheating increases with a concurrent reduction in the importance of solar heating of buildings. The latter was also illustrated with the analysis of global



Murska Sobota 2006-2015

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
V	0.0	0.0	0.0	0.0	0.0	0.0	**9.6**	0.0	0.0	0.0	0.0	0.0
C_{sh}	0.0	0.0	0.0	0.0	**8.5**	**43.2**	**46.7**	**54.8**	**12.6**	0.0	0.0	0.0
C_{sn}	0.0	0.0	0.0	**28.3**	**29.5**	**5.7**	0.0	0.0	**26.0**	**15.7**	0.0	0.0
R	0.0	0.0	**62.7**	**71.7**	**62.0**	**51.1**	**43.7**	**45.2**	**61.4**	**56.4**	0.0	0.0
H	**100.0**	**100.0**	**37.3**	0.0	0.0	0.0	0.0	0.0	0.0	**27.9**	**100.0**	**100.0**
S	0.0	0.0	0.0	0.0	**8.5**	**43.2**	**53.6**	**54.8**	**12.6**	0.0	0.0	0.0

Murska Sobota 1966-1975

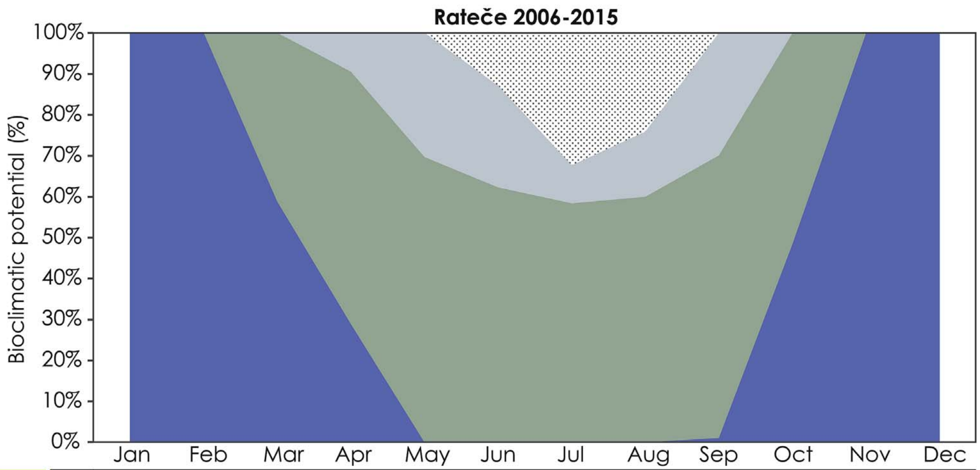
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
V	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_{sh}	0.0	0.0	0.0	0.0	0.0	**23.1**	**41.6**	**35.8**	0.0	0.0	0.0	0.0
C_{sn}	0.0	0.0	0.0	**23.2**	**33.7**	**15.1**	**4.6**	**6.4**	**31.2**	**11.8**	0.0	0.0
R	0.0	0.0	**56.7**	**70.2**	**66.3**	**61.8**	**53.8**	**57.8**	**68.8**	**52.4**	0.0	0.0
H	**100.0**	**100.0**	**43.3**	**6.6**	0.0	0.0	0.0	0.0	0.0	**35.8**	**100.0**	**100.0**
S	0.0	0.0	0.0	0.0	0.0	**23.1**	**41.6**	**35.8**	0.0	0.0	0.0	0.0

Fig. 5. Monthly breakdown of the bioclimatic potential for the location of Murska Sobota, during the periods of 1966–1975 (bottom) and 2006 to 2015 (top). V – high thermal mass and/or natural ventilation and shading needed, C_{sh} – comfort achieved with shading, C_{sn} – comfort achieved with solar irradiation, R – potential for passive solar heating, H – no potential for passive solar heating, $S = V + C_{sh}$ – shading needed.

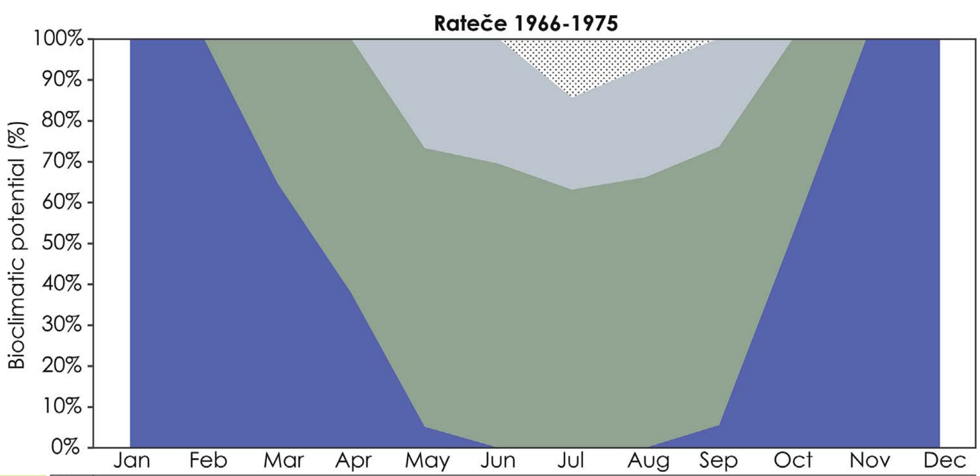
climate trends by Li et al. [62]. Furthermore, Ascione [52] emphasised the increasing importance of passive cooling technologies for mitigating global warming-induced overheating of buildings. The described trend is in contradiction to the prevailing view on building design – that buildings located in Central European locations with temperate climate, such as continental part of Slovenia, should be optimized solely for passive solar utilization. The same goes for the bioclimatic solutions found in vernacular architecture, as these were adapted to considerably different climatic conditions than those that are dominant today.

Moreover, if the above described trends are used for future predictions applying linear extrapolation for the upcoming two decades (2016–2025 and 2026–2035), the increased importance of overheating protection measures becomes even more evident (Table 4). In this way, the forecasted yearly period of S is increased most in Murska Sobota, where its value is predicted to rise up to 19.4% (2026–2035), which represents a 4.8% point increase in comparison to the years between 2006 and 2015. In comparison to the first analysed decade, with such trend the period of year when shading is needed will increase by 11% points. Similar results are true for the comparable locations of Novo mesto ($S = 17.7\%$) and Ljubljana ($S = 18.5\%$), while smaller increase is projected for Portorož ($S = 24.4\%$) and Rateče ($S = 8.6\%$).

These predictions of shifts in bioclimatic potential indicate that the most affected are and will be buildings situated at locations with temperate climate. In case of Slovenia these locations coincide with the most urbanised parts of the country, which means that a large portion of the existing building stock will be affected. As a consequence, an increase of cooling and a decrease of heating energy demand can be expected. Similar conclusions were drawn by Huang and Hwang [63], who demonstrated on a case of residential buildings in Taiwan that substantial increase in cooling energy use will occur due to the effect of global warming. However, it is unclear if the potential increment of cooling load will be nullified by the reduction in heating demand. The



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
V	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_{sh}	0.0	0.0	0.0	0.0	0.0	**12.9**	**32.3**	**24.1**	0.0	0.0	0.0	0.0
C_{sn}	0.0	0.0	0.0	**9.5**	**30.3**	**24.8**	**9.3**	**15.9**	**29.9**	0.0	0.0	0.0
R	0.0	0.0	**41.1**	**61.6**	**69.7**	**62.3**	**58.4**	**60.0**	**69.0**	**51.4**	0.0	0.0
H	**100.0**	**100.0**	**58.9**	**28.9**	0.0	0.0	0.0	0.0	**1.1**	**48.6**	**100.0**	**100.0**
S	0.0	0.0	0.0	0.0	0.0	**12.9**	**32.3**	**24.1**	0.0	0.0	0.0	0.0



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
V	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_{sh}	0.0	0.0	0.0	0.0	0.0	0.0	**14.4**	**6.9**	0.0	0.0	0.0	0.0
C_{sn}	0.0	0.0	0.0	0.0	**26.8**	**30.5**	**22.5**	**27.0**	**26.4**	0.0	0.0	0.0
R	0.0	0.0	**35.3**	**62.1**	**68.1**	**69.5**	**63.1**	**66.1**	**68.1**	**47.7**	0.0	0.0
H	**100.0**	**100.0**	**64.7**	**37.9**	**5.1**	0.0	0.0	0.0	**5.5**	**52.3**	**100.0**	**100.0**
S	0.0	0.0	0.0	0.0	0.0	0.0	**14.4**	**6.9**	0.0	0.0	0.0	0.0

Fig. 6. Monthly breakdown of the bioclimatic potential for the location of Rateče, during the periods of 1966–1975 (bottom) and 2006 to 2015 (top). V – high thermal mass and/or natural ventilation and shading needed, C_{sh} – comfort achieved with shading, C_{sn} – comfort achieved with solar irradiation, R – potential for passive solar heating, H – no potential for passive solar heating, $S = V + C_{sh}$ – shading needed.

latter is more likely to occur in colder climates (e.g. type D of Köppen-Geiger classification), as it was shown by Li et al. [62]. In order to clarify the exposed questions, present and future energy performances of one bioclimatic and one non-bioclimatic building were simulated and are presented in section 3.2.

3.2. Energy performance evaluation

The results of bioclimatic potential analysis showed that the most substantial change can be expected for the location of Murska Sobota (Tables 3 and 4). Therefore, the current and the predicted future energy performances of the selected two residential buildings (Fig. 3) were simulated at that location. Moreover, the location of Murska Sobota also exhibits similar climatic characteristics and changes in bioclimatic potential as the locations of Ljubljana and Novo mesto. The calculations were performed using EnergyPlus and input parameters described in section 2.3. The results for the 2006–2015 decade were used as a baseline and compared with the predicted future energy consumption for the years 2020 and 2050. The energy performance analysis considered the energy use for heating (Q_{NH}) and cooling (Q_{NC}) normalised per m^2 of floor area. Additionally, the cumulative ($Q_{NT} = Q_{NH} + Q_{NC}$) energy use was recorded. Energy performance of both analysed buildings was evaluated with respect to the influence of building envelope thermal characteristics and window optical characteristics (i.e. OLD, NEW envelope type), as well as the selected bioclimatic strategies (i.e. shading, window orientation and area, compactness of building form) present in the modelled buildings.

Results presented in Fig. 8 and Tables 5–7 show that the identified change in the climatic conditions and corresponding bioclimatic potential of the location will have a substantial impact on the future energy performance of the selected buildings. Predictably, in the coming decades a significant reduction in heating energy demand can be

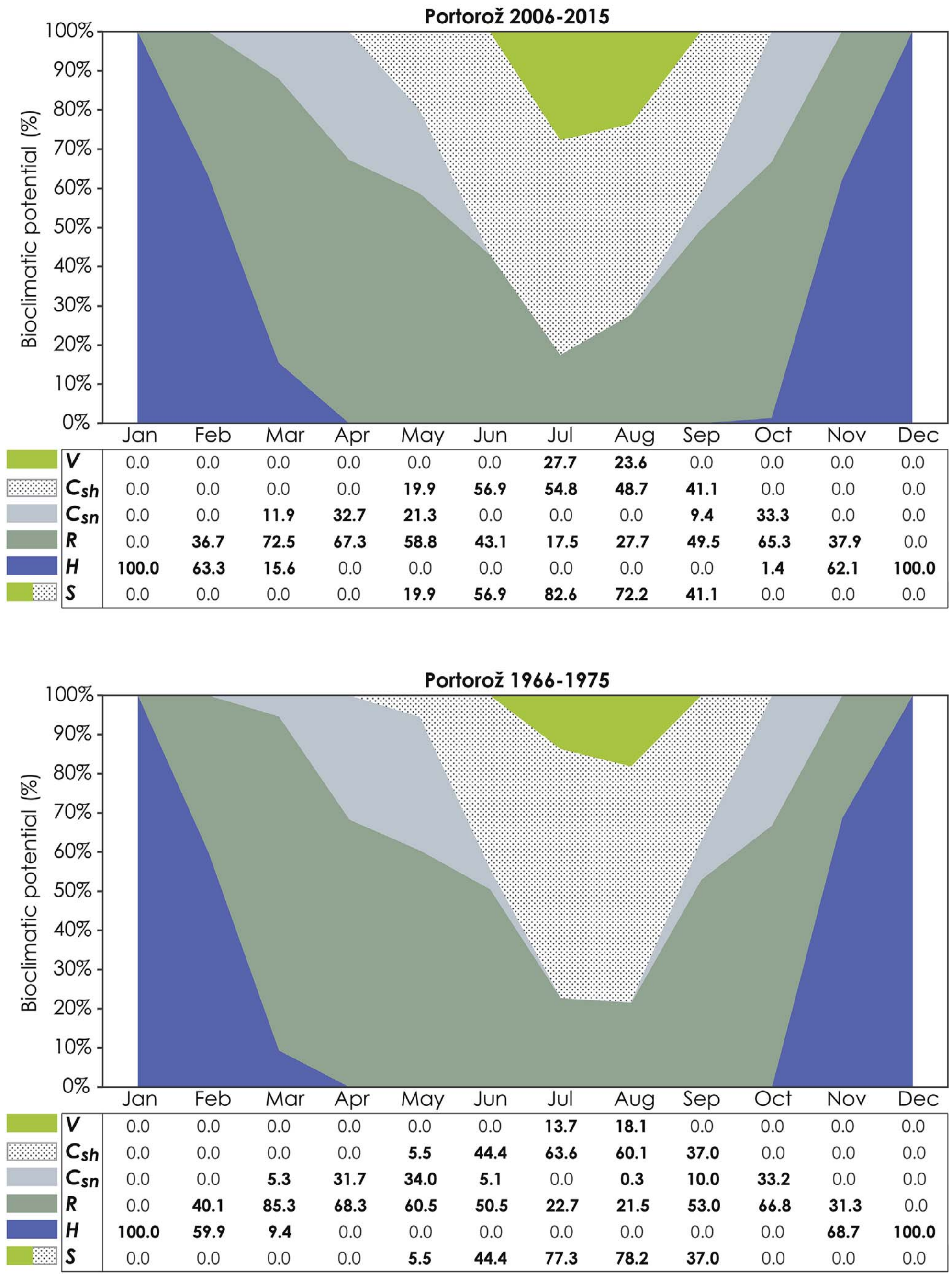


Fig. 7. Monthly breakdown of the bioclimatic potential for the location of Portorož, during the periods of 1966–1975 (bottom) and 2006 to 2015 (top). V – high thermal mass and/or natural ventilation and shading needed, C_{sh} – comfort achieved with shading, C_{sn} – comfort achieved with solar irradiation, R – potential for passive solar heating, H – no potential for passive solar heating, $S = V + C_{sh}$ – shading needed.

Table 4
Predicted future values of S (i.e. $V + C_{sh}$) – shading needed, C_{sh} – comfort achieved with shading, C_{sn} – comfort achieved with solar irradiation and the ratio between C_{sh}/C_{sn} for 2016–2025 and 2026–2035.

		Portorož	Ljubljana	Novo mesto	Murska Sobota	Rateče
2016–2025	S (%)	23.4	16.9	16.1	17.2	7.2
	C_{sh} (%)	17.6	14.3	14.0	14.1	5.6
	C_{sn} (%)	8.8	8.4	9.3	8.7	9.8
	C_{sh}/C_{sn}	1.99	1.69	1.51	1.62	0.57
2026–2035	S (%)	24.4	18.5	17.7	19.4	8.6
	C_{sh} (%)	17.5	15.3	15.3	15.7	6.6
	C_{sn} (%)	8.4	8.0	9.2	8.2	9.5
	C_{sh}/C_{sn}	2.10	1.92	1.67	1.91	0.70

expected for the BC building as well as for the non-BC building (Fig. 8). In the case of building envelope labelled as NEW (i.e. thermally insulated in accordance with current Slovenian legislation), the Q_{NH} for the BC building is projected to decrease by 15% (4.52 kWh/m^{2}a) and 26% (7.64 kWh/m^{2}a) by 2020 and 2050, respectively, in comparison to the current state (29.47 kWh/m^{2}a). In the case of the non-BC building the reduction is slightly larger with 19% (8.08 kWh/m^{2}a) in 2020 and 31% (13.23 kWh/m^{2}a) in 2050, while the current energy use for heating is 43.29 kWh/m^{2}a. Similar trend can also be noted for the thermal characteristics of the OLD envelope (Fig. 8). Due to the predicted increase in the need for overheating prevention, a substantial increase in cooling energy use can also be expected. This is confirmed by energy simulations, where the comparison of shaded and unshaded building models (Fig. 8) shows that by 2050 both buildings will become cooling dominated. For example, the Q_{NC} for the shaded BC building with NEW envelope type is projected to rise from 6.70 kWh/m^{2}a

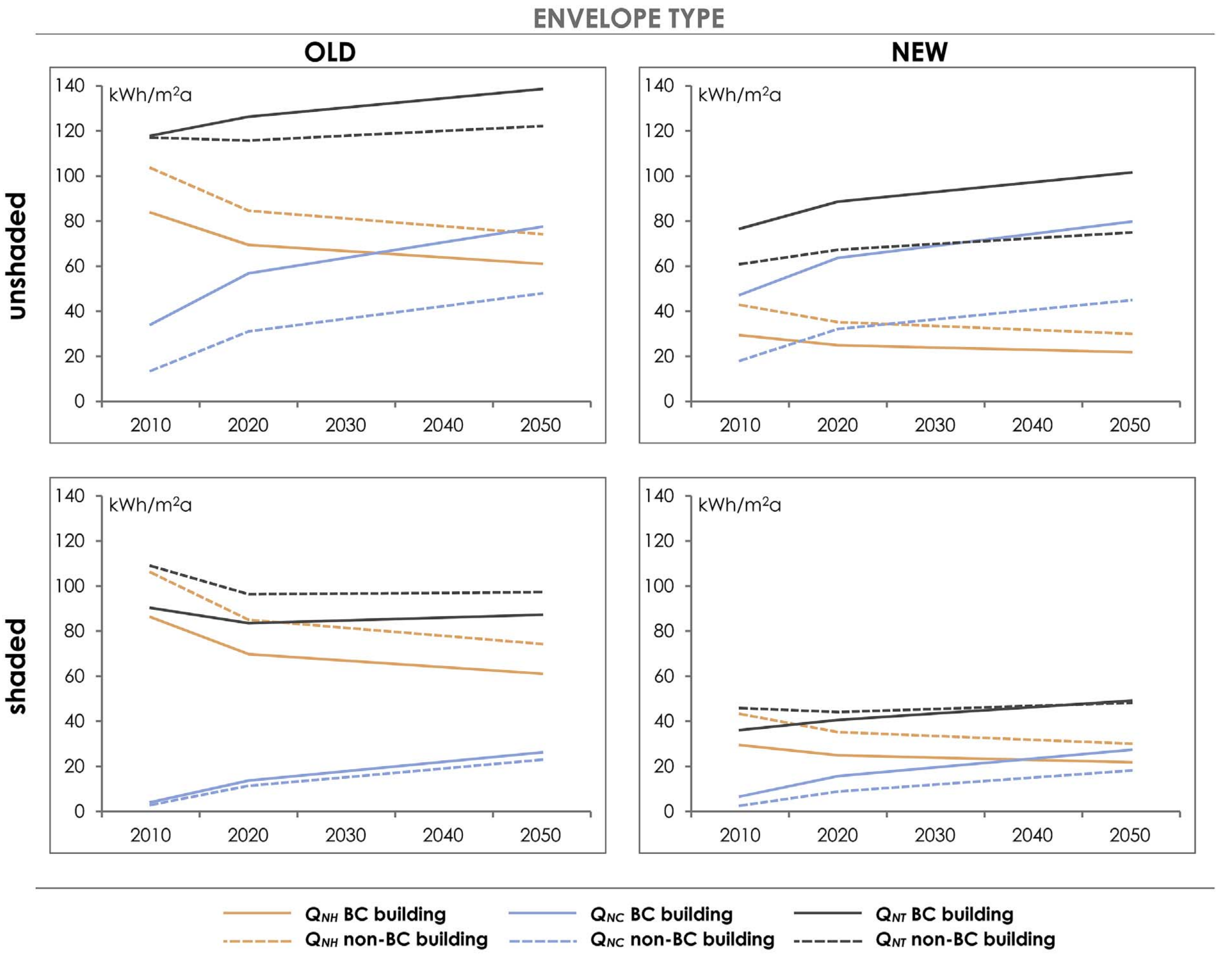


Fig. 8. Trends of present and future predicted energy consumption of the analysed BC and non-BC buildings.

(2006–2015 period) to 27.32 kWh/m^{2}a in 2050, which is a 308% increase. The impact is even greater in the case of unshaded buildings, where the BC building is currently already declared as a cooling dominated (Table 5). For the non-BC building the impact of climatic change on cooling energy use is significantly smaller due to the smaller area of windows and their orientation. The Q_{NC} for the shaded non-BC building with NEW envelope currently amounts to 2.58 kWh/m^{2}a, while the predicted value for 2020 is 8.89 kWh/m^{2}a and 18.17 kWh/m^{2}a for the year 2050.

Inspecting the value of Q_{NT} in Fig. 8, a trend emerges, whereas the cumulative energy use for all cases increases. In the example of buildings with NEW envelope and shaded windows (i.e. the most realistic configuration) the value of Q_{NT} in 2050 is in fact almost the same for the BC (49.15 kWh/m^{2}a) as for the non-BC building (48.23 kWh/m^{2}a). The latter demonstrates that the advantages of the BC building that was designed in order to enable better usage of solar gains during heating season will be nullified by the changes in climatic conditions and increase in cooling energy use. The only exceptions to the trend of increasing Q_{NT} are the shaded BC and non-BC buildings with OLD envelope, where the cumulative energy in 2050 (87.31 kWh/m^{2}a for the BC building and 97.28 kWh/m^{2}a for the non-BC building) is smaller than at present (90.33 kWh/m^{2}a for the BC building and 108.94 kWh/m^{2}a for the non-BC building). This is a consequence of the relatively small increase in the Q_{NC} as a result of shading and higher thermal transmittance of the building envelope, while at the same time the Q_{NH} is substantially reduced due to the increase in winter time ambient temperatures (Fig. 8).

3.2.1. Comments on the results of energy performance evaluation

The results of energy performance analysis of the two selected single family buildings exposed the trend of increased importance of cooling at the selected location of Murska Sobota in the upcoming decades. The increase in the cooling energy use will also result in the increase of the cumulative energy use of the analysed buildings. These findings correspond to the predictions of the bioclimatic potential evaluation presented in section 3.1. Similar conclusions were also drawn by Pierangioli et al. [43] on a case study conducted in central Italy for residential (single and multi-unit dwellings) as well as commercial office buildings. A comparable study conducted for the climate of the Netherlands by van Hooff et al. [40] also showed that due to climate change the number of overheating hours inside residential buildings will increase and consequentially the cooling energy use as well. Both referenced studies investigated the effect of different passive design measures (e.g. shading, increased ventilation, increased albedo of external building envelope, etc.) to counteract the impact of climate change on building energy performance. However, these measures were investigated on a typical building and not on buildings with bioclimatic features, which was the focus of the presented energy performance study. As it was described in the previous section, bioclimatic buildings (e.g. BC building) designed for temperate Central European climate presently outperform conventional buildings (Fig. 8 and Table 5). Nevertheless, this advantage will be reduced or completely eliminated in the forthcoming decades, as the relative importance of different design strategies will shift from passive heating (e.g. large windows, low thermal transmittance of building envelope, etc.) to prevention of overheating (e.g. shading of windows, smaller windows, increased

Table 5
Energy performance of the analysed buildings conducted under the present (2006–2015) climatic conditions for the location of Murska Sobota.

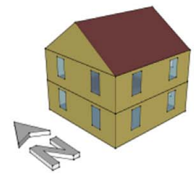
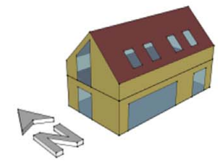
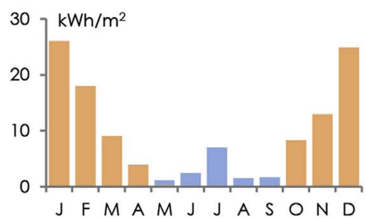
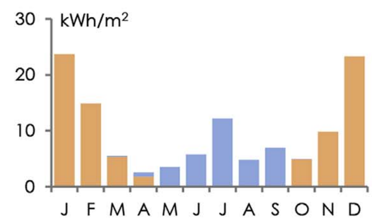
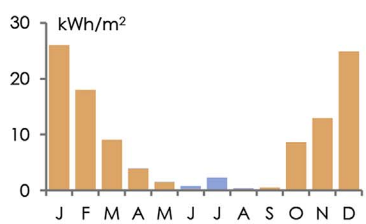
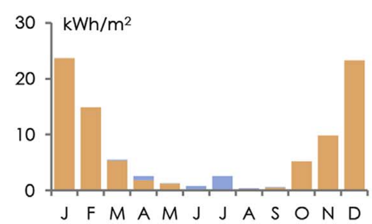
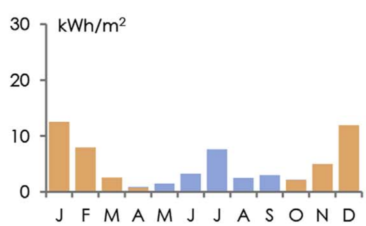
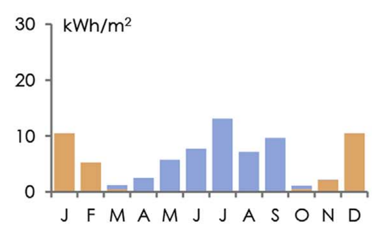
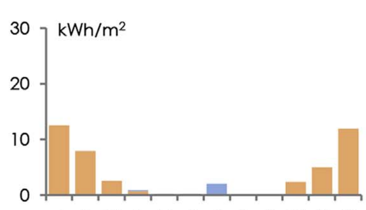
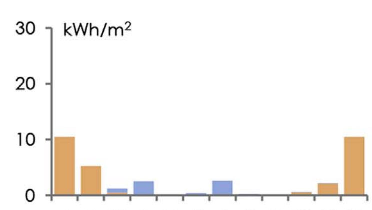
2006 – 2015 period				**non-BC building**	**BC building**
					
Envelope type					
OLD	**unshaded**	Q_{NH}	(kWh/m^{2}a)	103.49	83.74
		Q_{NC}	(kWh/m^{2}a)	13.55	34.17
		Q_{NT}	(kWh/m^{2}a)	117.04	117.91
					
	shaded	Q_{NH}	(kWh/m^{2}a)	106.03	86.21
		Q_{NC}	(kWh/m^{2}a)	2.91	4.12
		Q_{NT}	(kWh/m^{2}a)	108.94	90.33
					
NEW	**unshaded**	Q_{NH}	(kWh/m^{2}a)	42.78	29.35
		Q_{NC}	(kWh/m^{2}a)	18.10	47.27
		Q_{NT}	(kWh/m^{2}a)	60.88	76.62
					
	shaded	Q_{NH}	(kWh/m^{2}a)	43.29	29.47
		Q_{NC}	(kWh/m^{2}a)	2.58	6.70
		Q_{NT}	(kWh/m^{2}a)	45.88	36.16
					
		Legend		Q_{NH}	Q_{NC}

Table 6
Energy performance of the analysed buildings conducted under the predicted future (2020) climatic conditions for the location of Murska Sobota.

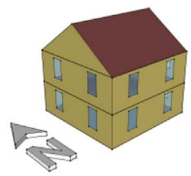
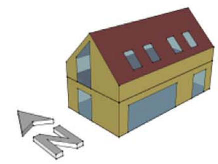
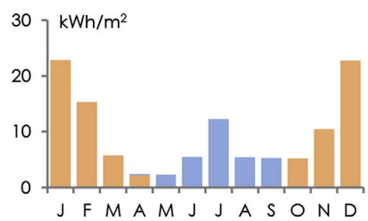
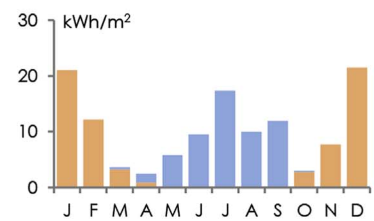
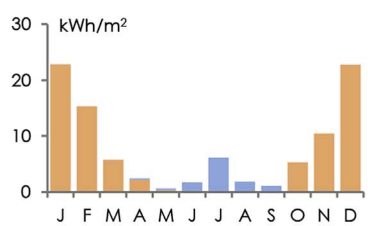
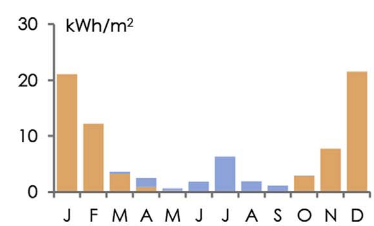
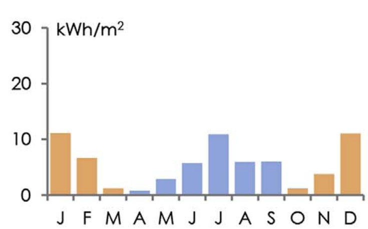
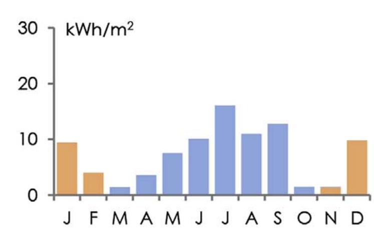
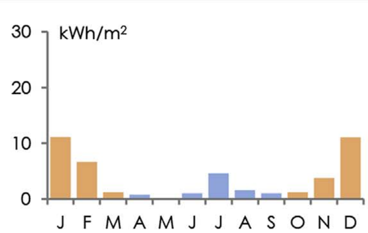
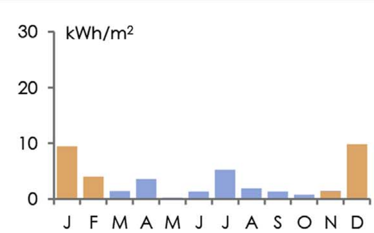
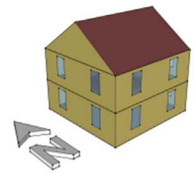
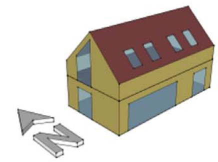
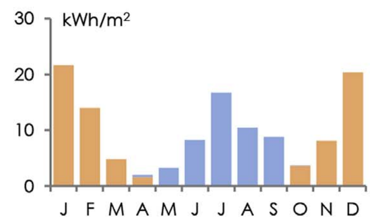
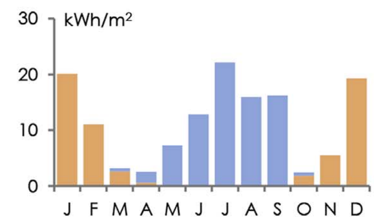
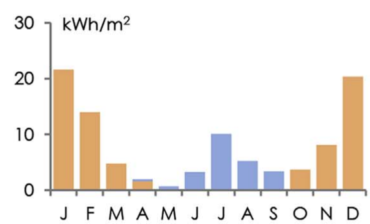
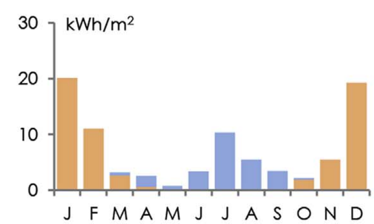
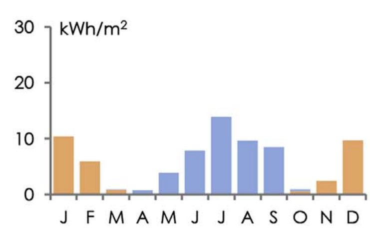
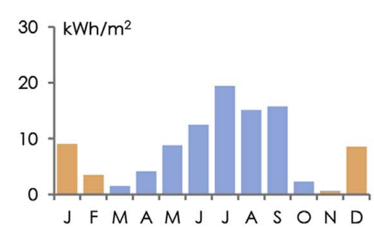
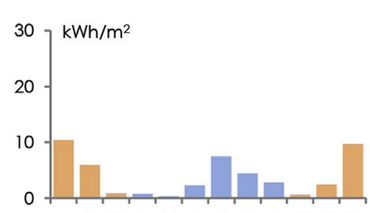
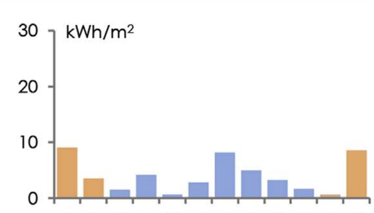
2020 prediction				non-BC building	BC building
					
Envelope type					
OLD	**unshaded**	Q_{NH}	(kWh/m^{2}a)	84.63	69.47
		Q_{NC}	(kWh/m^{2}a)	31.10	56.85
		Q_{NT}	(kWh/m^{2}a)	115.73	126.32
					
	shaded	Q_{NH}	(kWh/m^{2}a)	85.04	69.81
		Q_{NC}	(kWh/m^{2}a)	11.37	13.71
		Q_{NT}	(kWh/m^{2}a)	96.41	83.52
					
NEW	**unshaded**	Q_{NH}	(kWh/m^{2}a)	35.14	24.95
		Q_{NC}	(kWh/m^{2}a)	32.14	63.68
		Q_{NT}	(kWh/m^{2}a)	67.28	88.62
					
	shaded	Q_{NH}	(kWh/m^{2}a)	35.21	24.95
		Q_{NC}	(kWh/m^{2}a)	8.89	15.68
		Q_{NT}	(kWh/m^{2}a)	44.09	40.63
					
		Legend		Q_{NH}	Q_{NC}

Table 7
Energy performance of the analysed buildings conducted under the predicted future (2050) climatic conditions for the location of Murska Sobota.

2050 prediction				non-BC building	BC building
					
Envelope type					
OLD	**unshaded**	Q_{NH}	(kWh/m²a)	74.22	61.06
		Q_{NC}	(kWh/m²a)	47.93	77.51
		Q_{NT}	(kWh/m²a)	122.15	138.57
					
	shaded	Q_{NH}	(kWh/m²a)	74.32	61.14
		Q_{NC}	(kWh/m²a)	22.96	26.17
		Q_{NT}	(kWh/m²a)	97.28	87.31
					
NEW	**unshaded**	Q_{NH}	(kWh/m²a)	30.04	21.83
		Q_{NC}	(kWh/m²a)	44.92	79.72
		Q_{NT}	(kWh/m²a)	74.96	101.55
					
	shaded	Q_{NH}	(kWh/m²a)	30.06	21.83
		Q_{NC}	(kWh/m²a)	18.17	27.32
		Q_{NT}	(kWh/m²a)	48.23	49.15
					
		Legend		Q_{NH}	Q_{NC}

natural ventilation, etc.). These conclusions indicate that in order to take advantage of local climatic conditions, the current design paradigm should adapt to the predicted future trends. The stated is especially important when selecting the bioclimatic design strategies to be implemented in the design of bioclimatic buildings. The selected strategies should be thoroughly evaluated, not only with respect to the current or past climate, but also to the future state.

To summarise, the main implications of the conducted analysis in the context of building design are twofold. Firstly, with increased and rising importance of building overheating prevention (e.g. shading, intensive natural ventilation), thermal conditions in the existing building stock are called into question, since these buildings were designed decades ago. Because designers did not put emphasis on the overheating protection due to different climatic conditions, it can be argued that in such buildings thermal discomfort is on the rise [64] due to higher air temperatures. Consequentially, retrofit installation of mechanical cooling can become an issue in view of ever greater importance of building energy performance [64,65]. Secondly, the results show that any replication of current bioclimatic solutions, which are predominantly focused on passive heating, into contemporary buildings without critical evaluation is a risky undertaking. Even in the short time span of the analysed 50 years, substantial differences in bioclimatic potential and corresponding dominant passive solutions were identified. Additionally, the executed simulations for the predicted future energy performance of buildings confirm that current solutions in bioclimatic building design will become irrelevant or at least extremely inefficient by 2050. Therefore, it is necessary for the designers to critically reassess the presumptions of crucial bioclimatic elements at a specific location using current as well as predicted climatic data and to base their design solutions on such data. In this respect, even the most basic presumption of energy efficient building design should be reassessed. For instance, the notion of reducing building envelope thermal transmittance might become less important in the future when heating energy consumption will become smaller. In this respect, the proposition of Andrić et al. [44] that by 2050 building envelopes will have extremely low U values (e.g. $U = 0.08$ W/m^{2}K) might not present an optimal solution, at least not for the locations in the temperate climate. Therefore, the belief that thermal insulation should be ranked at the top of the most effective investments for energy savings in buildings [66] should be re-evaluated in the light of future climate change.

Furthermore, the changed ratio between heating and cooling energy use of buildings will also have a substantial influence on the supply energy mix of such buildings. With the increased cooling energy demand, the use of electricity would grow substantially. This would increase the load on the electrical power supply systems worldwide and increase CO_2 emissions because of the much higher carbon footprint of electricity [31,45]. In the final analysis, this is of special importance in case of the use of NEW envelope and shaded windows, where in 2050 the total energy consumption of BC and non-BC buildings will practically be the same. However, the BC building will have a noticeably higher cooling energy use and thus also a greater electricity consumption. It can be concluded that an overall environmental impact of such building will be larger than the impact of the non-BC building.

4. Conclusions

The results presented in the paper show the importance of climate analysis in the contemporary bioclimatic building design. The latter must be consistently adapted in order to facilitate appropriate functioning, not only for the current conditions but also for the future. Moreover, the existing buildings, the reaction of which to climate change is usually suppressed, should be renovated in accordance with the findings of this study. Thus, overheating prevention measures should be practiced in energy renovation actions as well. Although the legislation in this field is mostly focused on heating season and heat-loss prevention (e.g. prescribed maximum thermal transmittance), architects, engineers and other stakeholders in the building industry must be aware that in the future climate-adapted buildings in temperate climatic zones will have to confront overheating. In this context, the results showed that the shading season is expanding even towards the transitional months, such as April and October. These findings are of particular interest to construction industry, because bioclimatic buildings in temperate climate zone are predominantly designed on the basis of heating season and will not adapt to the future trends without deliberate interventions. Accordingly, the findings of this study suggest a need for a conceptual leap in bioclimatic building design in order to keep designers in step with the current and future challenges posed by climate change. This is especially important as higher level of thermal discomfort can occur in the future due to overheating of buildings.

Policy addressing building design and building energy renovations should be supplemented to encourage the incorporation of passive design strategies into buildings. Primarily, current focus on heating energy consumption reduction in buildings should be critically evaluated and supplemented in accordance to the predicted future trends. Only with such approach, bioclimatically designed buildings will become resilient buildings and the design solutions of today will also be sustainable in the future.

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